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# Demo: Assessing the need for 5G driven Edge and Fog solution for Digital Twin systems

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## ABSTRACT

This demonstration presents the solution for a robotic Digital Twin system that integrates Fog computing to offload the robot control logic. This solution is then used to demonstrate the problems that Digital Twin system may face when performing teleoperation over an unreliable and delayed link.

## CCS CONCEPTS

• Networks → Network experimentation; • Computer systems organization → Robotic control.

## KEYWORDS

Digital Twin, 5G, Edge and Fog, Latency, Reliability

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## 1 INTRODUCTION

With the rise of the next generation of 5G technologies (5G NR, NFV, Edge and Fog), Digital Twinning is paving the way for cyber-physical convergence and providing a new way to execute smart manufacturing, management and remote control. Virtual models of physical objects are created to replicate their behaviors in digital environments. The Digital Twin system is mainly composed of three components: (i) virtual models in the digital environment; (ii) physical objects in the real environment; and (iii) data that ties this two environments together.

In particular, the implementation of teleoperated Digital Twin systems can be used in dynamic (and eventually dangerous) environments to keep human operators safe and to significantly reduce operation costs. With the widespread of Edge [3] and Fog [2] computing paradigm, new opportunities arise for remotely operated Digital Twin systems by removing time-sensitive applications (e.g., control algorithms) from the physical objects and place them in the

close proximity of the end-users. Moreover, context networking information (e.g., communication links status) acquired from the access network can be used to adapt the physical objects' operations. As a result, it is possible to build lightweight, low cost, and smarter physical objects while exploiting the Edge and Fog distributed infrastructure to share the connected data between various virtual models for cooperative operation.

Despite the evident advantages that this paradigm offers to teleoperated Digital Twin systems, the network-assisted robotic concept is still far of being fully exploited and optimized. The distribution of the time-sensitive control logic between the physical objects and the infrastructure leads towards a new set requirements (including low latency, high reliability and availability and high bandwidth) that are placed over the underlying communication technologies.

Moreover, the mobile and smart manufacturing paradigm introduced by Industry 4.0, wireless connectivity is a necessity and current radio access technologies (RATs) (e.g., Bluetooth, WiFi, LTE) face limitations when trying to address the above mentioned requirements. Motivated by these needs, the fifth generation of mobile networks (5G) has defined ultra reliable and low latency communications (URLLC) [1], being very well positioned to overcome the shortcomings of current RATs.

In this demo paper, a proof-of-concept implementation of a ROS-based Robot Digital Twin system, that is distributed between the physical robotic system and external computing resources, is developed and showcased. The developed system is used to teleoperate a physical robot in near real time, demonstrating the problems that Digital Twin systems face when remote control operations are performed over unreliable or delayed IEEE 802.11 link.

## 2 SYSTEM DESIGN AND IMPLEMENTATION

Fig. 1 depicts the setup used for this demonstration: (i) 6-axis Niryo One<sup>1</sup> robot manipulator is used as the physical robot; (ii) a laptop (with 8GB of RAM and 4 vCPU) equipped with an Xbox 360 controller is used as an Fog node and device used by the teleoperator; and (iii) an WiFi (IEEE 802.11 ac) access point providing wireless connectivity. Both the Niryo One Robot and the laptop are also connected by a 10 GB/s Ethernet link.

The showcased Digital Twin system is implemented based on Robot Operating System (ROS)<sup>2</sup>, which modules are distributed across the robot and the laptop. The ROS *Driver* nodes are deployed in the robot, being responsible for (i) making available robot sensor data and operational states and (ii) executing manipulation

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<sup>1</sup><https://niryo.com/> [Accessed: 13 July 2020]

<sup>2</sup><https://www.ros.org/> [Accessed: 13 July 2020]

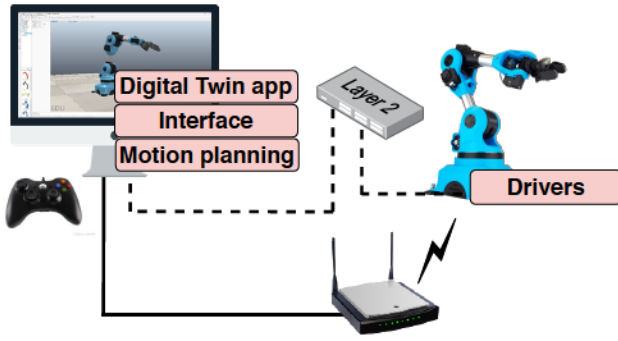


Figure 1: System design and implementation

commands. The remaining of the ROS modules are deployed in the laptop. The *Motion planning* is responsible for finding inverse kinematics and building a path for the robot. This path consists of a sequence of movements that are sent to the ROS drives following a given frequency. The loop is then closed by the robot continuously sending-back the current position. The top of the ROS stack consists on the *Interface* module which implements an high-level abstraction for the core Motion planning functionalities. This module can be seen as the gateway between the operator and the robot that ensures safe and optimal operations. Finally, an application is required (i.e., *Digital Twin app*) to combine all the modules and give human understanding of the connected data. The Digital Twin app implements a 3D model of the robot and a joystick remote control node.

### 3 DEMONSTRATION

This demonstration aims at showcasing the need for an 5G Edge and Fog solution for teleoperated Digital Twin systems. The attendee interfaces with the Digital Twin app to manipulate the robot in order to execute a pick-and-place task, shown in Fig. 2. The demonstration starts with the attendee trying to control the robot to pick an object from a box using the Xbox controller. Once the robot is in the right position, the gripper is used to pick the object, after which the attendee tries to move the robot towards himself so the object can be delivered. Upon a successfully delivery, a reward object is given to the robot and the attendee attempts to place this object in a reward box (tips box on Fig. 2). The attendee must performed the aforementioned demonstration by interfacing only with the virtual models.

This demonstration is executed under three different scenarios which cover different network conditions and communication technologies: (i) Ethernet-based scenario; (ii) WiFi latency scenario; (iii) WiFi packet-loss scenario.

**Ethernet-based Scenario.** In the Ethernet scenario, the attendee executes the demonstration over stable wired link with low latency and no packet loss. The attendee can perform a real-time remote control of the robot with the required precision to execute the demonstration. Additionally, the attendee will observe the virtual model being updated in near real time.

**WiFi Latency Scenario.** In the WiFi latency scenario, a constant artificial delay on the wireless link is introduced. While the

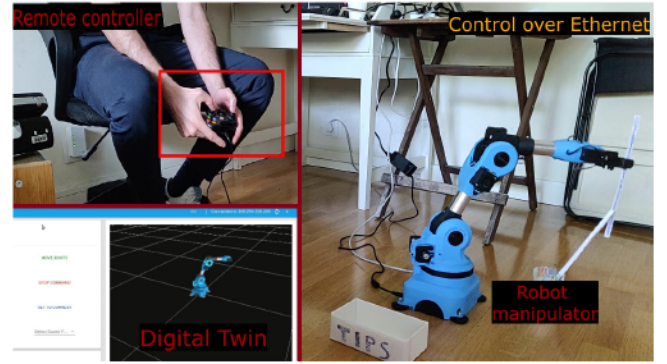


Figure 2: Digital Twin demonstration

attendee is executing the demonstration he will notice the effects of increased latency in teleoperated Digital Twin systems. As the increased latency between the Digital Twin app and the robot decreases the reaction time of the remote controller, the attendee might lose the required precision to perform the given task. Additionally, while navigating the robot, the attendee might observe how a burst of delayed control packets can be buffered and executed in a very fast sequence, resulting in an unpredictable and unwanted behavior by the robot. The increased latency might also force the attendee to operate on delayed data, which can be observed through the no synchronization between the robot and the virtual replica.

**WiFi Packet-loss Scenario.** In the WiFi packet-loss scenario, a constant artificial packet loss on the wireless link is introduced. While the attendee is executing the demonstration he will observe the effects of increased packet loss in teleoperated Digital Twin systems. The attendee might observe significant difficulties to control the robot in the presence of packet loss on the wireless link between the Digital Twin app to the robot. The robot might not react correctly to the executed commands of the attendee. In this case, unpredictable and uncontrolled movements from the robot might also be observed which makes the whole environment unsafe for operation. Moreover, the attendee might observe glitches in the Digital Twin app due to the lost packets that report the current pose of the robot. As a result, the attendee might face difficulties to execute the demonstration on such virtual replica.

### ACKNOWLEDGMENTS

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